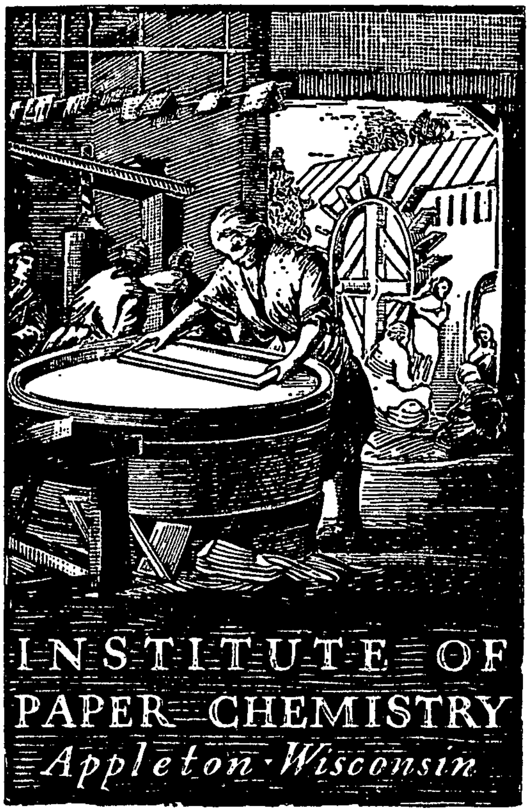

AN INVESTIGATION OF SINGLE-IMPACT TEST PROCEDURES

Part 1. Staircase Method

Project 2033

Report Twenty-seven

A Progress Report

to

MULTIWALL SHIPPING SACK PAPER MANUFACTURERS

November 7, 1962

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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MEMBERS OF GROUP PROJECT 2033

Albemarle Paper Manufacturing Co.

Continental Can Company, Inc.

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Olin Mathieson Chemical Corporation, Forest Products Operations

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

AN INVESTIGATION OF SINGLE-IMPACT DROP TEST PROCEDURES
PART 1: STAIRCASE METHOD

SUMMARY

Most common drop tests are fatigue tests by definition since the sack is repeatedly dropped until it fails. An alternative approach to sack evaluation is to estimate the height required to produce failure on a single drop. Fatigue characteristics of the sheet are not brought into play in this latter approach and the two types of drop tests may be expected to rank samples somewhat differently.

To investigate the above approach, two techniques were studied. They were the "Probit" and "staircase" methods. The Probit method appeared to require more sack testing than the "staircase" method. In addition, a cursory trial appeared to indicate that the response curve between per cent survival and drop height was not linear, thus complicating the analysis. For these reasons most attention was centered on the "staircase" method.

The "staircase" method permitted evaluation of both regular and extensible sack samples at 10% R.H. At 25% R.H. or higher it proved impossible to use the technique with the extensible sacks because many or all sacks failed to break on a single drop from 10 feet, the maximum height attainable in the Institute's tester. The technique is, therefore, usable if sufficient drop height can be obtained.

Single impact face results appeared to be significantly related to the conventional drop tests. However, the relationship does not appear to be ideal and some samples may be ranked quite differently by the various drop tests.

INTRODUCTION

The conventional sack drop tests are fatigue tests by definition since each sack is repeatedly dropped until it fails. On each drop the sack walls are stressed and, in general, some permanent deformation takes place. Under those circumstances it can be argued that tests on the previously unstressed sheet may not be sufficient to entirely describe sheet behavior in a fatigue process.

From one standpoint the above implies that failure in the field occurs after the sack has been subjected to a number of impacts. If such is the case, a fatigue type of laboratory drop test is indicated to obtain better correlation between laboratory and field performance. However, field performance involves a variety of situations. One simple alternative is that under certain situations a sack might have to sustain only a single impact. If it survived that impact then its performance would be considered satisfactory. For this situation, a laboratory fatigue type of drop test would appear to be less satisfactory and some direct method of evaluating single impact drop test performance might be preferred.

For these and other reasons, it was thought desirable to investigate experimental methods for evaluating the performance of sacks when subjected to a single impact. The present report discusses two procedures for evaluating single impact sack performance and presents results obtained using a "staircase" procedure.

BACKGROUND INFORMATION

Two methods suitable for evaluating single impact sack performance are:

a) Probit method

b) Staircase method

A description of both methods may be found in Reference (1) and additional material on the statistical aspects of the staircase method may be found in the textbook by Dixon and Massey (2).

"PROBIT" METHOD

For this particular application, the "Probit" method would require evaluating sacks at four or five different drop heights. Each sack would be dropped only once. At each drop height the number and per cent of the sacks failing on the first drop would be recorded. The percentage survival values would then be plotted against drop height, a straight line fitted to the data, and the drop heights required to give the desired per cent survival would be read from the graph. (Note: normal probability graph paper is usually used because such data often plot as a straight line on such paper.)

The stress level at which 50% (median) of the specimens may be expected to fail is the survival value commonly chosen. Other levels may be chosen if the stress levels and number of specimens tested at each level are properly selected. For example, Reference (1) recommends the following allocation of specimens between the various stress levels.

Expected Per Cent Survival	Relative Group Size
25-75	1
15-20, 80-85	1.5
10, 90	2
5, 95	3
2, 98	5

Assume, for example, that it was decided to test 10 specimens at drop heights where the per cent survival lay in the 25 to 75% range. Then, to maintain approximately equal precision, 30 specimens would be recommended where the per cent survival was near 95% and 50 specimens at the 98% survival value. The large number of sack tests required to obtain meaningful results at low or high per cent survival values is evident.

To estimate the drop height required to give 50% survival at least four drop heights are recommended, two giving per cent survival values below 50% and two above. Reference (1) gives detailed information regarding the analyses of "Probit" method data. In general, the analyses are based on the fact that per cent survival data usually define a straight line when plotted on normal probability graph paper. The analysis proceeds from this point by fitting a straight line to the data using the method of least squares.

STAIRCASE PROCEDURE

In the staircase method, the specimens are tested sequentially. In terms of single impact sack tests the method would be as follows:

a. Drop the first sack once from a height estimated to equal the mean strength of the sample.

b. If the first specimen fails, the next specimen is tested at a height one increment below the first drop height.

c. If the first specimen does not fail, the drop height would be increased one increment above the first drop height.

d. Continue testing, adjusting the height on each test depending on the prior results.

The data obtained for sacks fabricated from two runs of regular kraft sack paper are shown in Fig. 1 to illustrate the above process.

As is apparent in Fig. 1, the selection of the proper increment between tests is important. Ideally most of the tests should be made at three drop heights. The heights should be such that about 50% of the specimens survive at the middle drop height. Corresponding per cent survivals for the lower and upper heights would be 70 and 30%, respectively. In this connection, Dixon and Massey (2) suggest that the ratio of the increment to the standard deviation (d/σ) should be within the range of about 0.5 to 2σ. As may be noted in Fig. 1, a number of long runs between reversals were encountered. This suggests that increasing the increment in Fig. 1 from 6 to 12 inches might be preferred.

The main advantage of the staircase method is that testing is concentrated near the mean height to cause failure on one drop. Fewer specimens may be required as compared to the "Probit" method. However, Reference (1) suggests that at least 30 specimens be tested.

The analysis of "staircase" results is outlined in Reference (1) and the details are described in later pages under "Procedure."

TEST PROCEDURE

Probit Method

A limited trial of this procedure was carried out using pasted sacks from Run B from the materials described in Progress Report Twelve. The materials

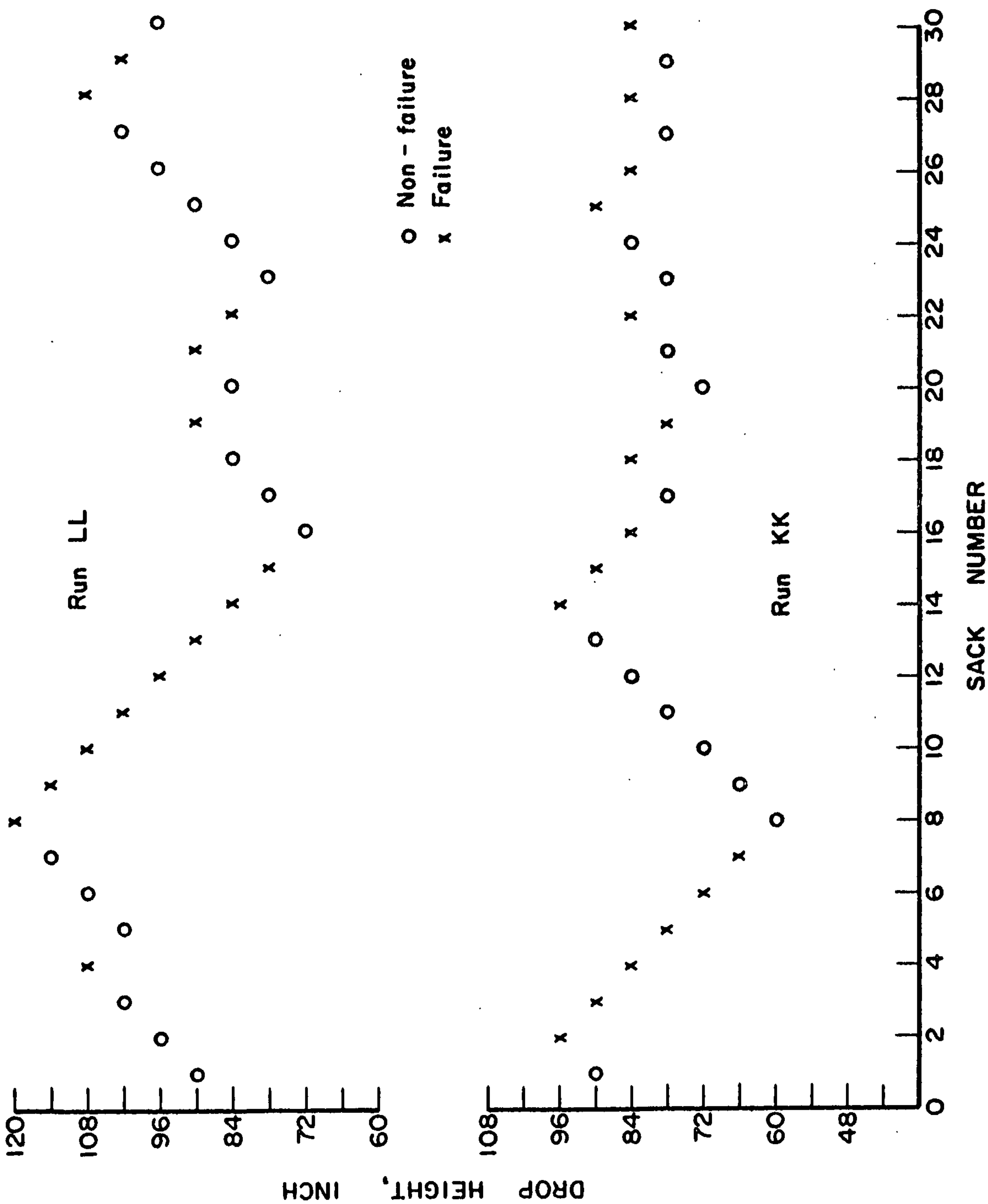

Figure 1. Graphical Representation of "Staircase" Procedure Test Results

and cement were conditioned at 50% R.H. and the following number of sacks were tested:

Drop Height, inches	Number of Sacks Tested
66	20
72	10
78	10
84	10
90	20

Each sack was dropped once on its face and the number of sacks failing at each height was recorded.

Staircase Method

1. Type of sack: pasted
2. Runs: AA through LL--regular kraft and MM through ZZ--extensible kraft.
3. Conditioning
   a. Test atmosphere: 10% R.H. and 50% R.H.
   b. Sacks: 24 hours at less than 35%, 48 hours in the test atmosphere.
   c. Cement: At least 5 days in the test atmosphere.
   d. Filled sacks: at least 0.5 hour in test atmosphere.
4. Vibration: as used previously.
5. Test Order:
   a. Fill and test ten sacks from each of three runs.
   b. Repeat (a) until 10 sacks from each run have been tested.
   c. Repeat (a) and (b) until 30 sacks have been tested.
6. Test Orientation: Test all sacks with valve to the right and face up.

7. Test Procedure:

   a. The ten sacks for any given run should be tested prior to starting tests on a second run.

   b. In (5a), drop the first sack from each run once at 7.5 feet.* If the sack fails, drop the second sack from 7.0 feet. If the sack does not fail, increase the height to 8.0 feet for the second sack. In general, in testing each succeeding sack from a given run,

      (1) Increase the height by six inches if the previous sack did not fail on the first drop.

      (2) Decrease the height by six inches if the previous sack failed on the first drop.

   c. Continue (6-b) until the ten sacks from a run are all evaluated.

   d. In the second and third rounds (see 5-c), drop the first sack from each run at the height established by the tenth sack from the previous round.

8. Record for each sack:

   a. Sack weight.

   b. Drop height in inches.

   c. Result--failure or nonfailure.

   d. Type of failure.

9. Calculations:

   a. Mean height to cause failure on first drop

      (1) Discard data up to the first pair of data giving opposite results [see Fig. 3 in Reference (1)].

      (2) Determine whether failures or run-outs are the less frequent event. Only the less frequent event is used in the analysis.

      (3) For each run, number the drop heights and prepare a table as follows:

*Note: A starting height of 4.5 feet was used for the regular sack tests at 10% R.H.

Drop Height, inches	i	N_i	$i\ N_i$	$i^2 N_i$
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
h_3	3	N_3	$3\ N_3$	$9\ N_3$
h_2	2	N_2	$2\ N_2$	$4\ N_2$
h_1	1	N_1	N_1	$1\ N_1$
h_0	0	N_0	0	0
		Sum =	A	B

where i = 0 is assigned to the lowest height on which the less frequent event occurs.
i = 1 is assigned to the height for $i_0 + d$, etc.
N_i = No. of less frequent events at each drop height.
$i\ N_i$ = product of i and N_i at each height
$A = \Sigma\ i\ N_i$
$B = \Sigma\ i^2 N_i$

(4) Estimate the mean height (m) by

$$m = h_0 + d\left(\frac{A}{N} \pm \frac{1}{2}\right)$$

where N = total number of less frequent events
d = height increment = 6 inches
h_0 = first height level

and use +1/2 if the less frequent event is a nonfailure
and use -1/2 if the less frequent event is a failure.

b. Standard deviation and error: The following equations were used to calculate the sample standard deviation (2)

$$s = 1.620\ d\left[\frac{NB-A^2}{N^2} + 0.029\right] \qquad (1)$$

where s = sample standard deviation
d, N, B, and A are defined in Part (a).

$$S.E. = \frac{Gs}{\sqrt{N}} \qquad (2)$$

where G = factor depending on d/s [values taken from Fig. 2, page 285 of Reference (2)]
and s and N are defined above.

DISCUSSION OF RESULTS

As mentioned previously, a limited trial of the "Probit" method was carried out using a sample of sacks fabricated from regular kraft. The results obtained are summarized in Table I and graphically illustrated in Fig. 2. It may be noted in the figure that a nonlinear relationship on normal probability paper was obtained. (Note: curves were also obtained in rectilinear and logarithmic co-ordinates.) Therefore, any statistical treatment of the data would be difficult. The above, coupled with the large number of sacks required--70 sacks were tested in the trial--suggested that work with this approach should be discontinued.

TABLE I

SUMMARY OF "PROBIT" METHOD RESULTS

Drop Height, inches	Number of Sacks Tested	Number of Sack Failures	Survival, %	Failure, %
66	20	5	75	25
72	10	3	70	30
78	10	4	60	40
84	10	6	40	60
90	20	17	15	85

Attention was then centered on the "staircase" procedure and the results obtained are summarized in Table II. It may be mentioned that the extensible sacks could not be evaluated at 50% R.H. because most sacks did not fail when dropped from 10 feet, the maximum height available in the Institute's drop tester. In fact, one of the regular kraft samples, Run JJ, could not be evaluated at 50% R.H. for

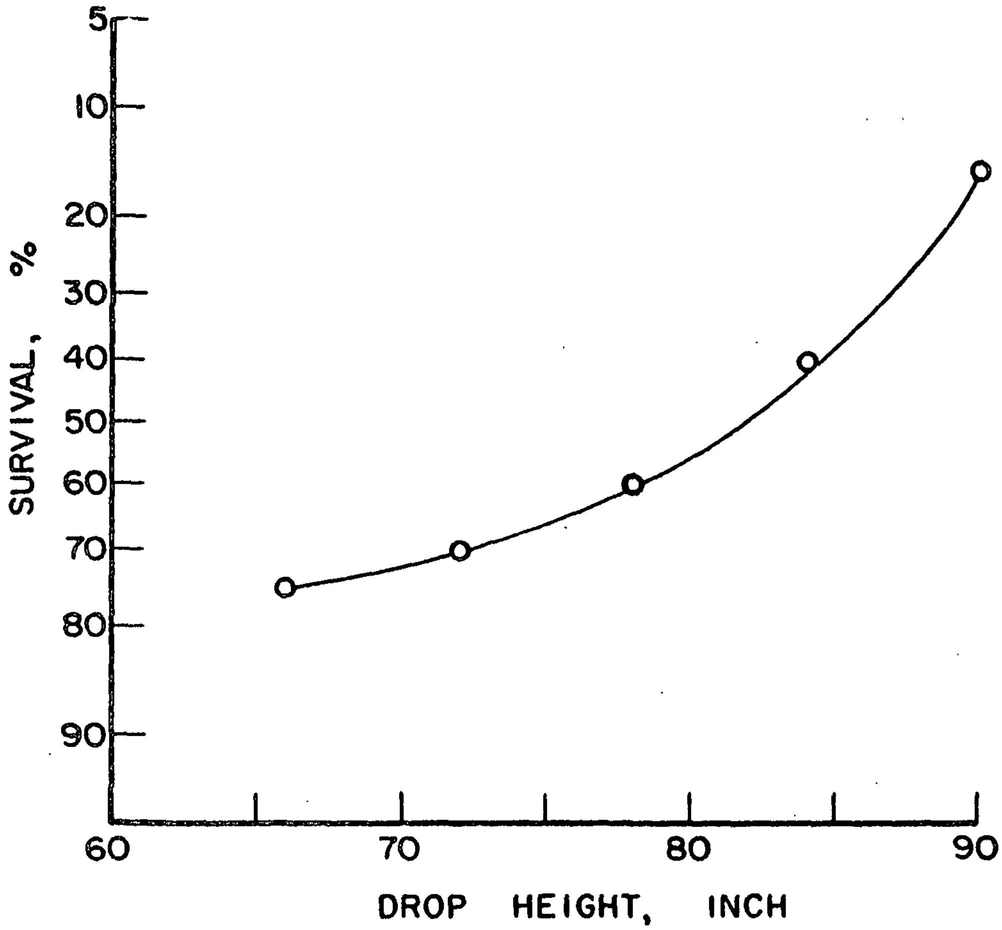

Figure 2. Response Curve for Single Impact Test Using Regular Kraft Multiwall Sacks

the same reason. [Note: Run JJ also exhibited the highest performance in the progressive height face and constant height butt drop tests.]

TABLE II

SUMMARY OF "STAIRCASE" PROCEDURE DROP TEST RESULTS

Single Impact Drop Height, inches

	Regular Kraft			
	10% R.H.		50% R.H.	
Run	Mean[a]	Standard Error, %	Mean[a]	Standard Error, %
AA	53	4.9	106	5.3
BB	42	5.7	89	2.9
CC	56	13.4	101	7.8
DD	49	3.5	80	7.5
EE	44	3.0	72	10.1
FF	43	8.1	83	4.8
GG	49	13.7	84	9.0
HH	51	14.5	84	5.2
II	48	5.6	101	5.7
JJ	54	7.0	--[b]	--[b]
KK	45	4.4	81	5.1
LL	42	8.6	95	9.4
Average	48	7.7	89	6.6
Max.	56		106	
Min.	42		72	

	Extensible Kraft	
	10% R.H.	
Run	Mean[a]	Standard Error, %
MM	89	3.3
NN	88	3.2
OO	99	2.6
PP	66	6.5
QQ	70	3.4
RR	67	2.5
SS	62	10.8
TT	72	2.9
UU	80	2.2
VV	83	4.2
WW	89	8.1
XX	64	5.9
YY	70	5.3
ZZ	67	3.3
Average	76	4.6
Max.	99	
Min.	62	

[a]Mean height to cause failure on a single face drop (staircase procedure).
[b]Sacks from this run did not break in first drop from the maximum drop tester height.

In Table II it may be noted that the results for the regular kraft samples decreased on the average from 89 to 48 inches or about 46% as the humidity changed from 50 to 10%. In Progress Report Twenty-six the corresponding figure was 77% for the "without insert" progressive height face drop test. Thus, there was less change in the height to cause failure on the first drop with relative humidity than in the progressive height drop.

If the average performance at 10% R.H. of the regular and extensible samples are compared it may be noted that the mean height to cause failure on a single drop was about 58% higher for the extensible samples. A comparable figure for the progressive height drop tests at 10% R.H. would be about 217%. Thus, at 10% R.H. the differences between regular and extensible sack performance was less in terms of single impact height than in terms of progressive height face drop.

As in the case of the progressive and constant height drop tests the variability was relatively high. Per cent standard error ranged from about 5 to 8% on the average. Thus, relatively large differences in mean height are required if they are to be considered statistically different.

The single impact results are compared to the conventional drop test results in Table III and a number of the relationships are graphically illustrated in Fig. 3 and 4. The graphs suggest that single impact drop results are related to progressive height face and constant height butt drop although the relationships are far from ideal.

The regression lines shown in Fig. 3 are tabulated in Table IV. As may be noted, neither correlation using 10% R.H. data was significant, however, correlations involving so little data should be viewed with caution. On the other hand, the correlation for the regular sacks at 50% R.H. was highly significant. The remaining relationships involving the combined data were highly significant as would be expected.

TABLE III

COMPARISON OF SINGLE IMPACT DROP TEST RESULTS WITH PROGRESSIVE HEIGHT AND CONSTANT HEIGHT BUTT DROP RESULTS

Run	Single Impact Face Drop Height, inches	Progressive Height Face Drop, safe drop	Butt Drop, safe drop
		50% R.H.--Regular Kraft	
AA	106	8.2	5.9
BB	89	7.6	3.6
CC	101	8.4	5.1
DD	80	6.6	3.2
EE	72	5.2	2.8
FF	83	5.5	2.6
GG	84	7.1	4.5
HH	84	6.8	4.8
II	101	7.5	4.8
JJ	--[a]	9.2	6.2
KK	81	6.1	4.8
LL	95	6.4	4.7
		10% R.H.--Regular Kraft	
BB	42	1.9	
EE	44	1.9	
GG	49	1.0	
II	48	1.7	
JJ	54	2.1	
KK	45	1.3	
LL	42	1.3	
		10% R.H.--Extensible Kraft	
MM	89	5.2	
NN	88	5.2	
OO	99	7.7	
PP	66	4.3	
QQ	70	5.0	
RR	67	6.0	
TT	72	4.7	
WW	89	5.8	

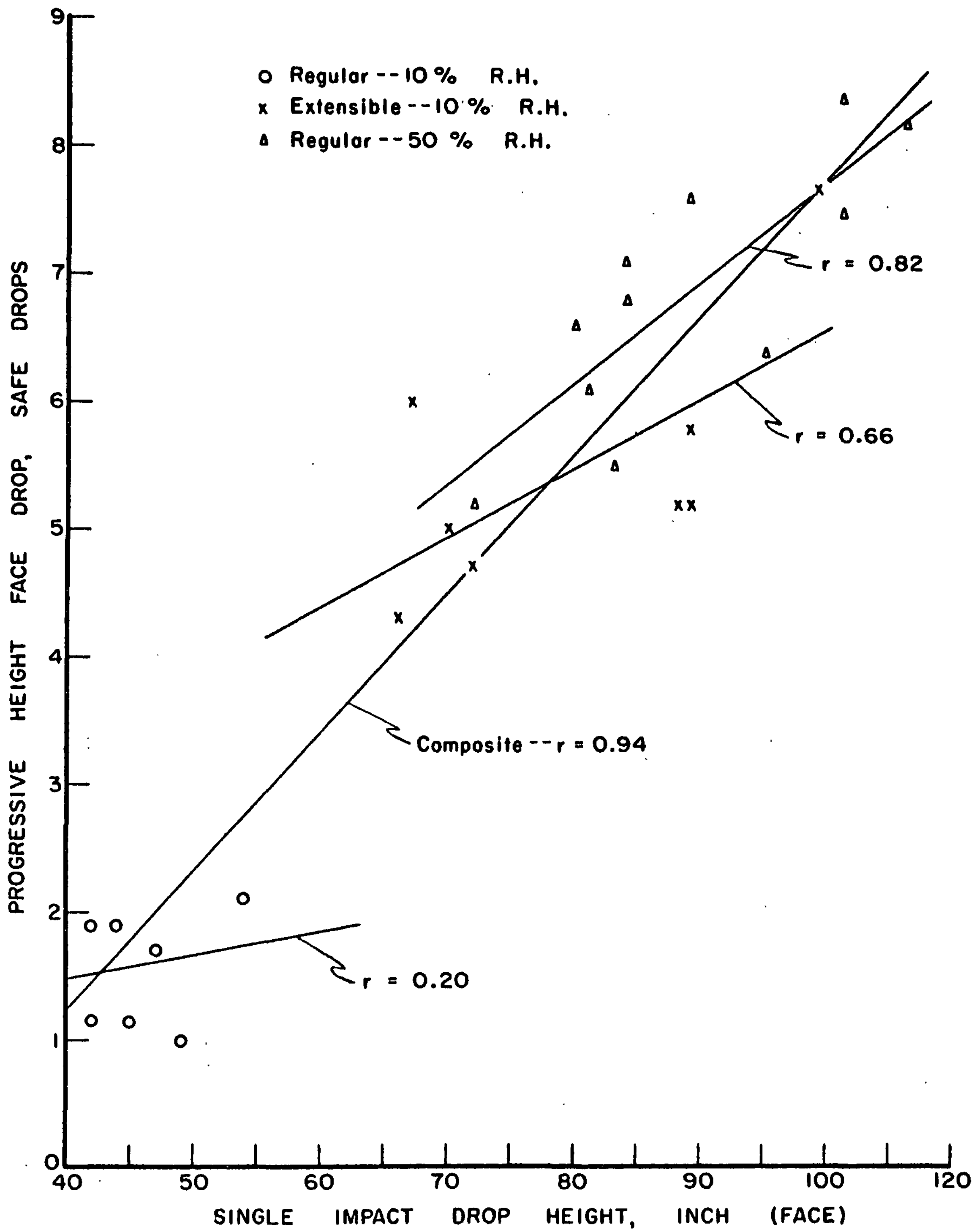

Figure 3. Relationship Between Single Impact and Progressive Height Face Drop Tests

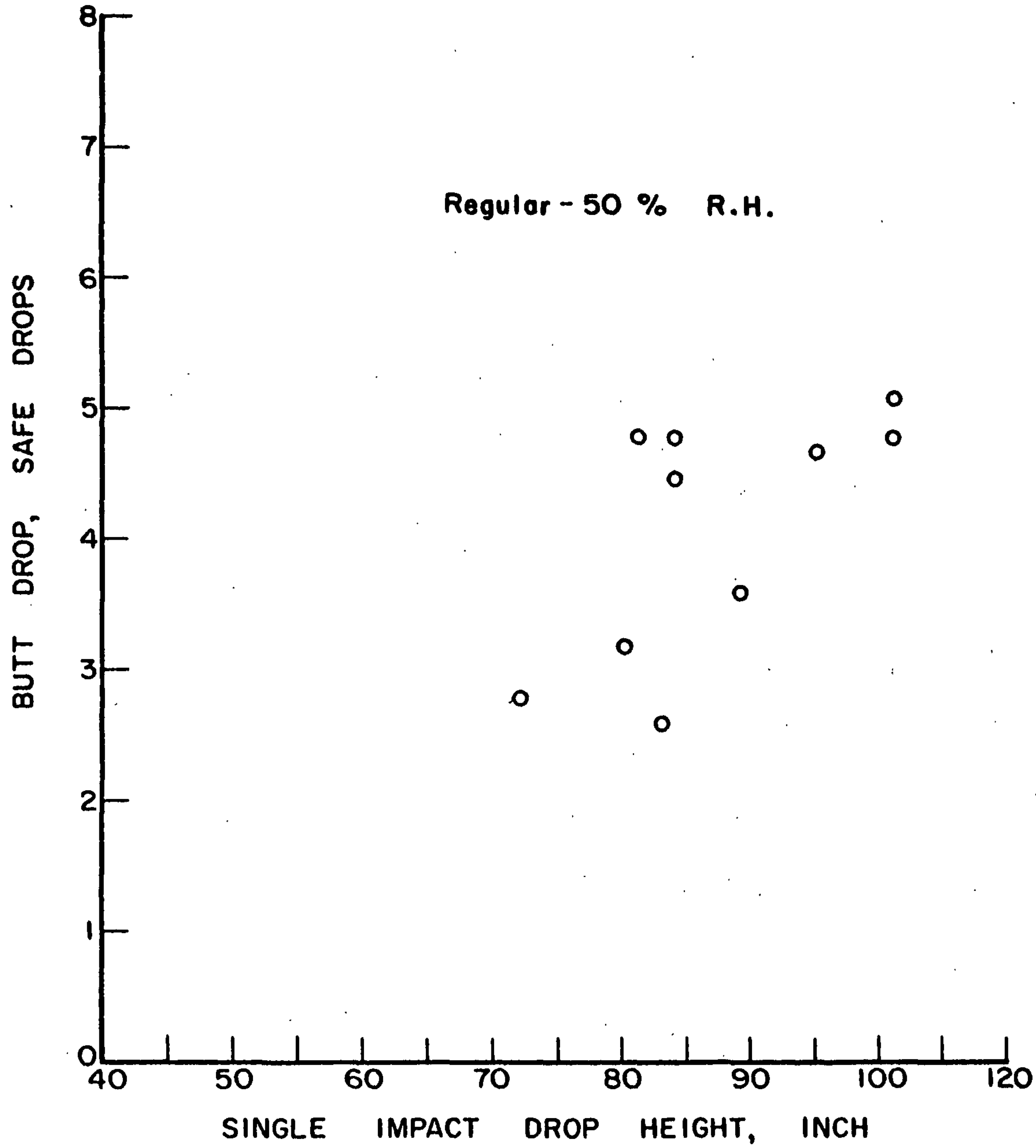

Figure 4. Relationship Between Single Impact Face and Constant Height Butt Drop

TABLE IV

SIMPLE CORRELATION OF SINGLE IMPACT FACE DROP HEIGHT WITH PROGRESSIVE HEIGHT FACE DROP

Data Subdivision	N	Relative Humidity, %	Regression Equation[c]	Correlation Coefficient	$\underline{F}$-ratio
1 Regular	7	10	$\underline{F} = 0.74 + 0.0185\ \underline{S_d}$	0.20	0.21
2 Extensible	8	10	$\underline{F} = 1.11 + 0.0548\ \underline{S_d}$	0.66	4.62[a]
3 Regular plus Extensible	15	10	$\underline{F} = -2.81 + 0.101\ \underline{S_d}$	0.93	77.9[b]
4 Regular	11	50	$\underline{F} = -0.20 + 0.0795\ \underline{S_d}$	0.82	18.5[b]
5 Combined 3+4	26	10, 50	$\underline{F} = -3.13 + 0.1092\ \underline{S_d}$	0.94	188.4[b]

[a]Significant at 10% level.
[b]Highly significant (beyond 1% level).
[c]Symbols: $\underline{F}$ = progressive height face drop, safe drop;
$\underline{S_d}$ = mean single impact drop height, inch.

The results in Fig. 3 were also subjected to an analysis of covariance using IBM program 6.0.032. A description of the technique may be found in Progress Report Twelve. As used herein, the analysis was employed to determine if a) the single impact and progressive height face drop data were significantly related and b) whether the slopes of the regression lines for the 10% regular, 10% extensible, and 50% regular were significantly different.

As may be noted in Table V, the regressions within the data groups were significant and the slopes of the three lines were not significantly different. The latter suggests that a line of constant slope might be fitted to the three data groups.

TABLE V

ANALYSIS OF COVARIANCE RESULTS

I Significance of average regression within group

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F
Regression	9.946,496	1	9.946,496	23.4**
Residual	9.369,534	22	0.4249	
Total	19.316,030	23		

**Highly significant

II Significance of differences between slopes

Source of Variance	Degrees of Freedom	Mean Square	F
Differences among group regressions	2	0.301,002	0.69
Deviations from ind. group regressions	20	0.438,376	
Deviations from av. regression within groups	22		

The butt drop vs. single impact results shown in Fig. 4 were not correlated. However, it appears from the figure that the two tests are related to some degree.

The relationship of the single impact results to various paper properties was studied using the results for the 50% R.H. regular kraft samples. The correlation coefficients are shown in Table VI, together with corresponding results for the progressive height face drop test. In general, the correlations were much the same, although some allowance must be made in allowing for the absence of Run JJ results in the single impact correlations.

TABLE VI

CORRELATION OF SINGLE IMPACT DROP RESULTS WITH PAPER PROPERTIES FOR REGULAR SACKS AT 50% R.H.

Test	Single Impact Face Drop (N = 11)	Progressive Height[a] Face Drop (N = 12)
1. Tensile, in	-0.03	0.29
2. Tensile, cross	0.15	0.05
3. Stretch, in	0.81	0.68
4. Stretch, cross	0.53	0.75
5. T.E.A., in	0.56	0.65
6. T.E.A., cross	0.56	0.70
7. Frag, in	0.21	0.56
8. Frag, cross	0.69	0.80
9. Impulse, in	0.44	0.55
10. Impulse, cross	0.37	0.70
11. T.A. impact fatigue	0.57	0.69
12. Scattering coefficient	0.16	--

[a]Taken from Table XIV, Progress Report Twenty-one.

A number of years ago Anderson and Ihrman (3) found that constant height drop tests on grocery bags were exponentially related to both drop height and commodity weight, i.e.,

$$\bar{n} = \frac{h_1}{h}^{a}$$

and $$\bar{n} = \frac{m_1}{m}^{b}$$

where $\bar{n}$ = drop number

h = drop height

h_1 = extrapolated drop height at $n = 1$

m = commodity weight

$\bar{m}$ = commodity weight at $n = 1$.

It would be of interest to determine if similar relationships held for multiwall sacks and to compare extrapolated values of h_1 at $n = 1$ with measured values based on both the single impact and Probit methods.

To briefly summarize it appears that

1) The "staircase" procedure may be satisfactorily used to estimate the mean height to cause failure on a single drop under some conditions. Factors to consider are:

   a) the increment between successive drops, and

   b) the maximum (and in some cases the minimum) height permitted by the drop test equipment. Maximum heights in excess of 10 feet may be required for some plain kraft multiwall sacks and for many extensible samples. Other combinations of materials could easily demand inordinately high heights.

2. Single-impact face results appear to be significantly related to both progressive height face and constant height butt drop tests. While many samples are ranked in much the same order by any of the drop tests, other samples are ranked differently.

3. The single impact face drop results were related to about the same type of test properties as the progressive height face drop test.. Thus, stretch, T.E.A., Frag, and impulse tended to exhibit most correlation with the single-impact results.

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